The indium-lead (In/Pb) binary system offers numerous alloy combinations. These materials possess mechanical and physical properties which make them useful in many demanding applications. With small additions of silver (Ag), additional alloys are created, rounding out this set of materials and providing us with a full set of performance capabilities. This is especially valuable in the electronics assembly soldering arena.

With melting temperatures ranging from 154°-313°C, this alloy family offers numerous choices for accommodating temperature sensitive applications, as well as step-soldering operations. In/Pb alloys also possess metallurgical properties that make them particularly suitable for soldering to thick Au metallizations.

Assemblers should not be dissuaded from using this versatile alloy family just because the joints that they form may not have the same visual characteristics that Sn/Pb and Pb-Free alloys have.

**Soldering to gold**

The tin-lead (Sn/Pb) alloy family has historically produced the most-used solder compositions. Standard Sn/Pb compositions are: Sn63 (63Sn/37Pb – eutectic composition), Sn62 (62Sn/36Pb/2Ag) and Sn60 (60Sn/40Pb). These alloys have proven to be excellent for soldering to tin, nickel (Ni), and other standard metallization schemes. In fact, due to their pervasiveness, metallization schemes were created just to suit these solders.

Non-standard applications, such as high-reliability, military, satcom, etc., require different material sets – some of which do not respond well to Sn-based solders. One highly relied upon metallization is gold (Au). Sn63 will dissolve approximately 1 micron (40 micro-inches) of Au per second per unit area at 200°C. Furthermore, studies have shown that, when the Au content of the solder joint reaches or exceeds 4% by weight, the resultant solder joint becomes unacceptably brittle, whereas Pb-Free or “SAC” (Sn/Ag/Cu) alloys start to exhibit brittleness at ~10% Au by weight. As a result, Sn/Pb alloys are only suitable for use with thin immersion-plated Au metallizations. This gold “flash” is typically <0.38 microns (15 micro-inches) and is used as a sacrificial layer to preserve the solderability of the underlying Ni layer.

Thick Au metallizations are quite prevalent in high reliability/critical applications. This thicker Au layer protects the device from corrosion, even in harsh environments, ensuring reliability. It is quite common for military specifications to call out Au platings on the order of 100 micro-inches (2.54 microns). Obviously, Sn/Pb alloys cannot be used in such scenarios due to the large volumes of available Au which would readily produce brittle solder joints.

The compatibility of In/Pb alloys with Au metallizations has been extensively demonstrated in two papers by F.G. Yost of Sandia National Laboratories. He documented observations that strongly support the use of In/Pb against thick Au. Key findings include:

- At 250°C, eutectic Sn/Pb is capable of dissolving Au at a rate 13 times greater than 50In/50Pb.
- In order to study the intermetallic layer that forms between 50In/50Pb and Au, a specimen was aged at 150°C for 40 hours. The reaction layer was quite ductile, with a Knoop hardness of 84.6 (compared to Au at 61.8, and soft Ni at 108.3). Yost explains this phenomenon by saying that the AuIn, intermetallics that grow during ageing are “embedded in a lead rich phase”. Another source offers, “The results of this testing suggest that the alloys (AuIn, AuIn) which form in the bond region are stable, non-brittle in thin film form…”

Yost did note that there are situations where In/Pb may not be the best option. Two of these situations are directly related to the thickness of the Au metallization:

- “To avoid excessive scavenging” of the Au and In/Pb alloys are not recommended against metallizations thinner than 1 micron (40 micro-inches). (It is the opinion...
of the author that this is not necessarily a problem, assuming that there is a solderable metallization, such as Ni, beneath the Au for the solder to bond to.)

- “Because of void problems, it is recommended that Pb/In solder should not be used on Au films thicker than 10 microns.” Yost found that Au layers with thickness of 10 microns < X < 15 microns lead to the depletion of In at the reaction interface. This causes the formation of Au-rich intermetallics, such as Au9In4. In a sample aged at 150°C for 40 hours, Yost noticed voids forming at the Au-Au9In4 interface. “These voids widened and eventually covered considerable portions of the Au interface.”

In certain situations, In/Pb alloys should be used cautiously against Au in applications with high operational temperatures. Honeywell research offers the following:

- “The microstructure developed at 125°C is suggestive of recrystallization. The coarse microstructure developed at 125°C is detrimental to the mechanical and electrical integrity of the bond.”
- “Couples aged at 125°C had zones which were non-uniform, had large columnar grains and large voids.”

CTE mismatch

Some electronics applications require that materials with markedly different coefficients of thermal expansion (CTE) be joined. Other situations subject the final assembly to repeated extreme temperature excursions. Due to excellent ductility characteristics, the In/Pb alloy system offers exceptional thermal fatigue resistance. It has been reported that when exposed to temperature cycling (-55°C – 125°C), the “fatigue life of lead-indium (50/50) solder joints averages about 100 times greater than tin-lead joint fatigue life.” In/Pb alloys absorb the stresses created by bonded materials possessing different coefficients of thermal expansion.

Some higher temperature In/Pb alloys, such as 95Pb/5In and 92.5Pb/5In/2.5Ag have been selected for service in automotive “under-the-hood” applications, which offer CTE differences and extreme temperature excursions. Also, their high, 300°C+ melting temperatures help them to withstand the operational temperatures that can be associated with engine compartment electronics.

Thermal and electrical conductivity

Indium has respectable thermal and electrical conductivity when compared to traditional electronics assembly materials, including solders. As points of reference, the thermal conductivity of Kovar is 17W/m·°K and the electrical conductivity of Sn63 (standard Sn/Pb) solder is 11.5% IACS (Figures 3-4).

Additional mechanical and physical properties of In/Pb alloys

The mechanical strength of In/Pb alloys is notably greater than their parent metals. They are generally strong enough to be used as direct replacements for the Sn/Pb family. Some of the high Pb-containing In/Pb alloys offer more strength than their Sn/Pb counterparts (Figure 5 and Table 2).

A technical paper issued by Texas Instruments wrote that the “elec-
The addition of Ag to certain In/Pb alloys can also impact alloy strength. Two examples of such Ag containing alloys are 80In/15Pb/5Ag and 92.5Pb/5In/2.5Ag. The Thermal Coefficient of Expansion of In/Pb alloys is similar to that of the Sn/Pb alloy family (25-30 ppm/°C), as shown in Figure 6. This is another example where In/Pb alloys could be used in applications where Sn/Pb alloys may have been designed in.

Corrosion concerns

In/Pb alloys exhibit poor corrosion resistance when exposed to high humidity (85%RH) and temperature (85°C). In a paper from the IBM System Products Division, it was observed that corrosion products containing In(OH)3, formed under the conditions previously stated, in which PbSn has been found to be stable. They go on to say that the presence of chlorides has been found to stimulate the reaction.

It would be prudent to consider an appropriate conformal coating, or other protection, for In/Pb joints that are exposed to humidity and/or halides.

Wetting properties and solder joint workmanship

Neither IPC J-STD-001D or IPC-A-610A devote much attention to solder joint workmanship for non-standard or specialty alloys. This can impose a significant challenge to assemblers required to meet IPC criteria. There is some verbiage in both IPC documents, but neither offers significant direction to assemblers when assessing “non-standard” solder joints, such as those made with an In/Pb alloy. Below is an excerpt that captures the extent to which current IPC documents cover these scenarios.

“...Wetting cannot always be judged by surface appearance. The wide range of solder alloys in use may exhibit from low or near zero contact angles to nearly 90 degree contact angles as typical. The acceptable solder connection shall indicate evidence of wetting or adherence where the solder blends to the soldered surface.”

In an attempt to address the lack of workmanship criteria for “non-standard” joints, a simple experiment was performed by the author to give some visual guidance as to what can be expected of In/Pb based alloys. The experiment was performed on clean copper coupons for the sake of availability and low cost, as compared to thick Au plated metallizations. (It should be noted that, when soldering to a

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**Table 2 – Tensile/Shear strength of InPb, InSn and InPbAg solders**

<table>
<thead>
<tr>
<th>Alloy (% by Weight)</th>
<th>Tensile (PSI)</th>
<th>Shear (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95Pb/5Sn</td>
<td>4000</td>
<td>2100</td>
</tr>
<tr>
<td>95Pb/5In</td>
<td>4330</td>
<td>3220</td>
</tr>
<tr>
<td>95Pb/5In/2.5Ag</td>
<td>4500</td>
<td>2650</td>
</tr>
</tbody>
</table>

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**Figure 5 – InPb Tensile/Shear strength**

**Figure 6 – Thermal coefficient of expansion of InPb alloy at 20°C**

**Figure 7 – Sn63 (left image - preform; right image - paste)**
thick gold plated surface, the solder joints may actually appear grainier depending on how much gold goes into solution in the solder joint.) Select alloys were chosen to represent the spectrum of In/Pb alloys. Solder preforms and paste of each alloy were used. The dimensions of the preform were selected to roughly equal the respective solder paste deposits. Sn63 and SAC305 alloys were also reflowed as controls. All preforms were reflowed using the same generic ROL1 tacky flux. The amount of flux applied was not controlled. This means that the amount of flux residue will vary, but is in no way a function of the alloy. Fluxes optimized to specific alloys may produce better wetting. All reflow was performed in air with an appropriate profile.

This simple experiment demonstrates that In/Pb solder joints are noticeably more grainy in appearance and may exhibit less wetting than their Sn/Pb and Pb-Free counterparts. The solder joint appearance should not alarm assemblers when attempting to build to IPC workmanship requirements.

**Pb-free legislation**

Many see the current RoHS legislation in Europe as an obstacle to using In/Pb alloys due to the Pb content. This legislation will definitely have an impact on some applications, particularly for commercial products. It is strongly recommended that concerned parties consult the RoHS Directive and pay special attention to item #7 in the annex.

**Undeniably valuable**

The value and potential contribution of the In/Pb solder alloy system is very meaningful in the modern electronics world. In/Pb alloys are virtually necessary when thick Au metallizations are required. Their uses are as wide and varied as the range of In/Pb alloys itself. Many applications can and do benefit from the properties and performance that these alloys offer. Assemblers should not be deterred from using these alloys simply because they may not look the same as “common” Sn/Pb and Pb-Free alloy solder joints.

Note: References are available on request from ebastow@indium.com. All charts in this work are best-fit curves based upon available data.